EFFECTS OF NEW DEICING ALTERNATIVES ON AIRFIELD ASPHALT CONCRETE PAVEMENTS

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ABSTRACT

Maintaining sufficient traction between the tires and the pavement is essential to achieve safe and efficient aircraft operation. For this purpose, large amounts of deicers/anti-icers are used every year for snow and ice control on Canadian airfield pavements, where the traditional deicing chemical is urea. However, because of environmental concerns related to the use of urea, alternatives deicing chemicals being considered by Canadian airport authorities. The potential deleterious effects of these alternative deicers on pavement materials need to be quantified and compared with those caused by the conventional deicer. The main objective of this paper is to complement previous studies by Transport Canada and Carleton University to assess the destructive effect of alternative runway deicers and to evaluate the impact they may have on the durability of asphalt concrete pavements. With previous studies focusing mainly on the damage during freeze-thaw cycles, the experimental program presented in this paper was designed to address the damage during wet-dry cycles following the freeze-thaw. Core samples were immersed in solutions made of urea, sodium formate, sodium acetate and potassium acetate and then subjected to 15 freeze-thaw cycles. Since most chemical reactions are quite slow at subzero temperature, the reaction between the asphalt concrete and the chemical residues of deicers may occur in the hot summer months rather than during the winter. Therefore, core samples were subjected to 40 wet-dry cycles, following the 15 freeze-thaw cycles. Control samples were immersed in distilled water and were subjected to the same number of cycles. The testing program involved weighing the samples at the end of each five cycles to investigate the trend of weight change. The samples were then tested for their indirect tensile strength, and the asphalt cement was extracted from the cores and tested for penetration. The results showed that none of the samples suffered clear disintegration as result of exposure to freeze-thaw and wet-dry cycles. Samples immersed in distilled water and all deicing solution suffered a decrease in the indirect tensile strength and elastic modulus during freeze-thaw, with the distilled water samples showing the greatest loss of both strength and elasticity. After the wet-dry test, both the strength and elasticity rebounded for almost all solutions, with the sodium acetate samples showing the greatest overall loss of strength and elasticity. The results of extraction test showed that freeze-thaw might cause a slight softening of the asphalt cement while wet-dry might cause slight hardening. The gradation of recovered aggregates of conditioned samples showed no significant difference from the dry samples.

INTRODUCTION

At Canadian airports, snow is normally cleared as it falls and before it accumulates. However, under certain conditions and as traffic continues to roll, the snow will get compacted by traffic and will bond to the pavement, making it difficult to remove with plows (*1*). Therefore, removal of snow and ice on the runways and taxiways is an important winter maintenance task that can be facilitated by the use of either a deicing or an anti-icing chemical (*2*). The traditional deicer at Canadian airports is urea, which has been used for years with no apparent damage to pavements. However, a few years ago in response to concerns about the potential effects of urea on the environment, alternative deicers were explored and are being used at some airports in Canada and in other countries. However, the potential damaging effects of these new deicers on airfield pavements need to be assessed before full-scale adoption of any of these new deicers. Towards this end, Transport Canada retained the services of the Department of Civil and Environmental Engineering, Carleton University to conduct a study in order to evaluate the relative destructive effects of various de-icing chemicals on asphalt concrete materials and mixes (*3*,*4*).

The study included two main phases. The first phase addressed two types of aggregates commonly used in Canadian airfield pavements. Aggregate samples were immersed in solutions of different deicers and subjected to freeze-thaw cycles, and the destructive effect of each deicer was evaluated in terms of aggregate weight loss. The second phase, on the other hand, addressed asphalt concrete mixes using core samples extracted form the Ottawa Macdonald/Cartier International Airport. The cores were immersed in deicing solutions and were subjected to freeze-thaw cycles. The destructive effect of the deicers in this case was evaluated in terms of change in the samples weight, tensile strength, elastic modulus, penetration of their recovered asphalt, and gradation of their recovered aggregates. Both phases utilized control samples that were immersed in distilled water and subjected to the same number of freeze-thaw cycles as the test samples. In addition, the second phase utilized dry core samples. The results of both phases showed that, compared to sodium formate, potassium acetate, and sodium acetate, urea caused the greatest damage in terms of sample disintegration, loss of strength, and loss of elasticity. However, most of the damage due to exposure to urea was evident in the samples subjected to 50 freeze-thaw cycles. Furthermore, exposure to freeze-thaw cycles was found to cause softening of the asphalt cement while the deicers caused hardening.

However, it was thought that concurrent exposure to freeze-thaw and a deicer may retard any damage instigated by chemical interaction between the asphalt and the deicer. This is based on the hypothesis that the deicers can inflict damage on the asphalt concrete in three possible ways. Firstly, it may increase the ice pressure within the asphalt concrete pores during freezing; secondly it may react chemically with the asphalt cement and reduce the ductility and/or reduce the binding capacity of the cement; and thirdly it may be a combination of the two. High pressure induced during freezing and its release after thawing would subject the asphalt concrete to high level of fatigue and thus may cause fatigue damage. The previous investigation would have revealed the effect of change in pore pressure during freeze-thaw cycles, but not the effect of chemical reaction in a dramatic fashion. The reason is that most chemical reactions practically cease at sub-zero temperature. Therefore, the chemical effect can be determined if the asphalt concrete is exposed to wet-dry cycles in the presence of deicing solutions at higher temperatures. This would simulate the effect of the absorbed deicers in the asphalt concrete during the summer months whereby wetting and drying cycles at higher temperatures occur. Therefore, a second investigation was recommended to examine the chemical effect of the deicers on hot mix asphalt concrete pavements at relatively high temperatures. In the following sections, the test procedure and results are described and discussed.

EXPERIMENTAL INVESTIGATION

The experimental program consisted of four main tasks.

Task 1: Preparation of Test Samples

Asphalt concrete cores with approximately 100 mm diameter and 65 mm height were obtained from a paving project at the Dorval International Airport. The dimensions and weights of 51 core samples were recorded, and the density of each core was determined. The maximum, average, and minimum densities of the cores were found to be 2400, 2354, and 2303 kg/m^3, respectively. The data were later used to divide the samples into sets with approximately the same mean density and dimensions.

Task 2: Selection and Preparation of Deicer Solutions

The same deicer types and concentration used in the earlier study (*3,4*) were used in the current investigation. The deicers comprised urea, sodium formate, potassium acetate, and sodium acetate. Each deicer was used to prepare a solution of 2% concentration, which was found to be the critical concentration in the earlier study. To achieve this concentration, the amount required for a fully saturated solution of each deicer type was taken equal to the amount determined in the previous study. These amounts were 0.870, 0.697, and 0.455 kg/litre for the urea, sodium formate, and sodium acetate, respectively. As for potassium acetate, which is a liquid deicer, full saturation was assumed to occur at 1:1 ratio of the chemical and the distilled water. The 2% concentration was then prepared by adding 2% of the amount required for full saturation. Finally, to separate the effects of deicers from the effects of freeze-thaw and wet-dry cycles, additional samples were immersed in distilled water.

Task 3: Conditioning Samples in Deicer Solutions

As mentioned earlier, the main objective of this investigation was to evaluate the damage to asphalt concrete mixes under warm temperatures after being subjected to a limited number of freeze-thaw cycles. Therefore, six cores were retained in their dry state as reference and 45 cores – 9 samples per solution type, including the distilled water – were immersed for 24 hours in the deicing solutions or distilled water at room temperature to achieve a saturated condition. Thereafter, they were surface-dried and weighed. The samples were re-immersed in the solution for another 12 hours and once again surface dried and weighed. If the difference between two consecutive weightings was found to be less than 1%, it was assumed the specimen had reached the saturated condition. All the samples reached saturation after 48 hours of immersion in the deicing solutions or distilled water, and thus the initial saturated-surface-dry weight of the samples, henceforth referred to as saturated weight, was determined.

The samples were then immersed in the deicing solutions and subjected to 15 alternating freeze-thaw cycles. The freeze cycles were achieved using the environmental chamber at Carleton University, where the temperature was maintained between –20 and –40º C for 24 hours. The main criterion for selecting the preceding temperature and the duration of freezing was full freezing of the solutions within the first 12 hours of the freeze cycle. For the thaw cycle, the samples were left at room temperature for 48 hours. In this case, thawing of solution generally occurred within the first 24 hours of the cycle. Figure I shows the samples in their containers that were placed in the environmental chamber during the freezing cycle. To assess the progress of damage during freeze-thaw, the change in the saturated sample weights was determined at the end of every five cycles. To determine these weights, the samples were taken out of the deicing solution, surface dried and weighed.

After the completion of the 15 freeze-thaw cycles, three specimens per solution type were left to dry out at room temperature and humidity conditions and weighed after 0, 4, and 7 days of drying. The samples were then tested for the mechanical and physical properties as outlined in

Task 4. The remaining specimens (6 cores per solution type) were subjected to 40 wet-dry cycles, where both wetting and drying cycles took place in the environmental chamber at a temperature of 40º C. The wetting cycle was two days, where the samples were immersed in the same solution used in the freeze-thaw cycles, followed by one day of drying. Figure II shows the samples in a dry cycle inside the environmental chamber. After the completion of the wet-dry exposures, the samples were tested as outlined in Task 4.

Figure I.
Freeze cycle in the environmental chamber.

Figure II.
Dry cycle in the environmental chamber.

Task 4: Testing Mechanical and Physical Properties

To assess the effect of each deicing solution and the effect of freeze-thaw and wet-dry cycles on the asphalt concrete pavement, Task 4 involved testing the mechanical properties of the asphalt mix and the physical properties of the mix components. First, the indirect tensile strength of the asphalt cores was determined. Subsequently, the asphalt cement was extracted from the asphalt concrete to determine its penetration grade and to determine the aggregate gradation. As mentioned earlier, these tests were performed on three samples per solution type after exposure to 15 freeze-thaw cycles and on six samples per solution type after exposure to 15 freeze-thaw and 40 wet-dry cycles combined. The same tests were also performed on the dry control samples.

OBSERVATIONS AND TEST RESULTS

Weights and Densities

After 15 freeze-thaw cycles, no noticeable damage or particle break up was observed in any sample. It should be noted that this observation is consistent with the earlier study where initial damage was observed after the 15th freeze-thaw cycles (*3*,*4*). First, the saturated weight of the specimens was recorded as stated earlier. The recorded weights are shown in Figure IIIa where the symbols DW, PA, SF, UR and SA denote distilled water, potassium acetate, sodium formate, urea and sodium acetate, respectively. The normalized average weights in the figure were calculated by dividing the average weight of each set after a specified number of freeze-thaw cycles by its saturated weight before the commencement of the freeze-thaw process. The figure shows that all specimens gained weight during the freeze-thaw cycles. As the number of freeze-thaw cycles increased, the rate of weight gain for the samples immersed in deicing solutions decreased. This trend continued during the wet-dry cycles where the saturated weight kept increasing at decreasing rate as the number of cycles increased (Figure IIIb).

Similar to the previous study, this increase in weight could be explained by the hypothesis that the samples were not initially fully saturated before the commencement of the freeze-thaw cycles. Therefore, the samples absorbed more liquid as the freeze-thaw progressed. Alternatively, or possibly concomitantly, the freeze-thaw caused micro cracks within the specimens, allowing the solution to reach previously air-filled voids. To test the validity of this hypothesis, the dry weights of the samples were determined at the end of the freeze-thaw and wet-dry processes. Figure IV shows the normalized average dry density of the samples, where the normalized average dry density is the average dry density after the indicated drying period divided by the initial, i.e. before immersion in the solution, dry density of each set. As shown in the figure, the average dry density decreases gradually as the drying period increases. This indicates that the main source of this weight increase is absorbed moisture.

Indirect Tensile Strength

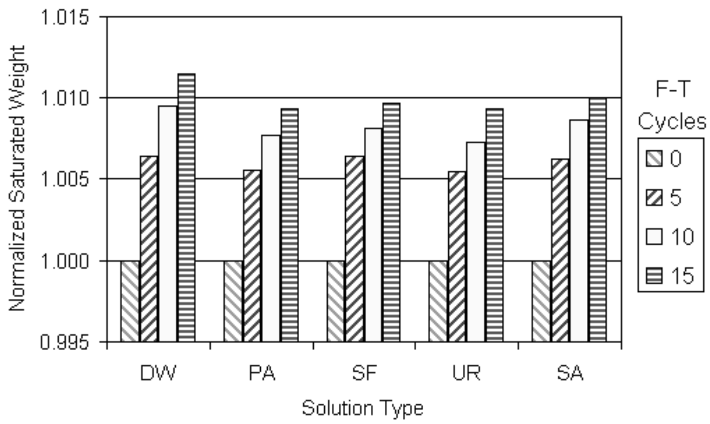
As mentioned earlier, for each deicing solution, three samples after 15 freeze-thaw cycles and six samples after 15 freeze-thaw cycles and 40 wet-dry cycles were tested for their indirect tensile strength. In addition, six dry samples (DS) were also tested. For each sample, the load was increased gradually at the rate of 50 mm/min until the maximum or peak load was reached.

The load was then released and re-applied at the same rate till failure. The samples failed in a split mode that is through the formation of a diametrical crack in the vertical plane. The collected data were used to plot the stress-strain diagram for each core sample. For example, Figure V shows the stress-strain diagram for the six dry samples. It should be noted that, the indirect tensile stress and the corresponding strain at any point of the test were calculated as follows:

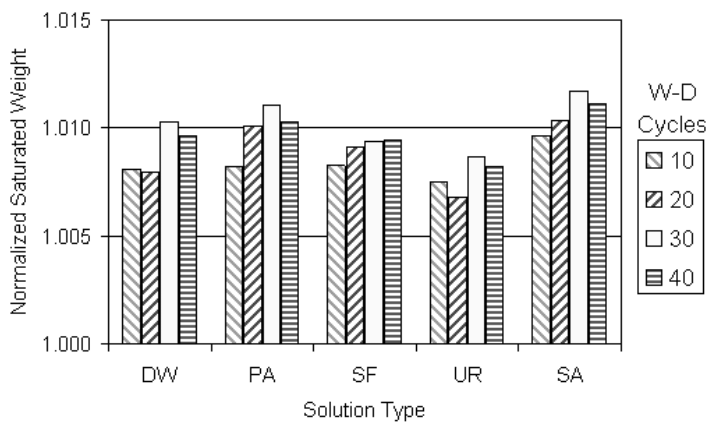
$$\text{Stress (MPa)} = \frac{2P}{\pi\, D\, h} \tag{1}$$

$$\text{Strain} = \frac{\Delta}{D} \tag{2}$$

where P = applied load (N), D = core diameter (mm), h = core height (mm), and Δ = vertical displacement (mm).



(a) During freeze-thaw (F-T) cycles.



(b) During dry-wet (D-W) cycles.

Figure III.
Change of normalized saturated weight during freeze-thaw and wet-dry cycles.

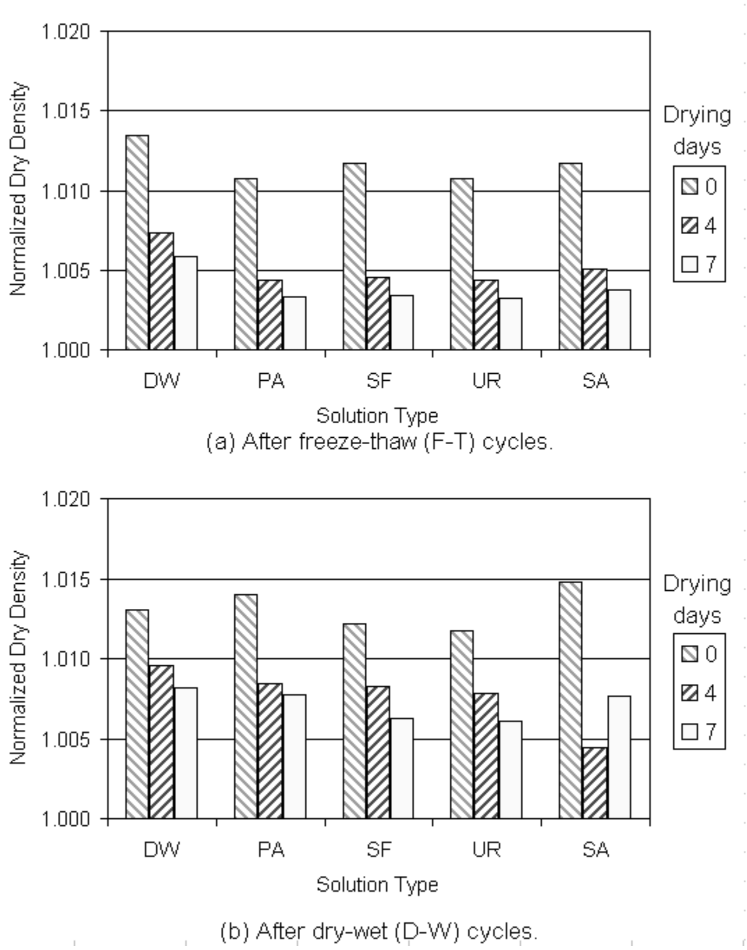


Figure IV.
Change of normalized dry density after freeze-thaw and wet-dry cycles.

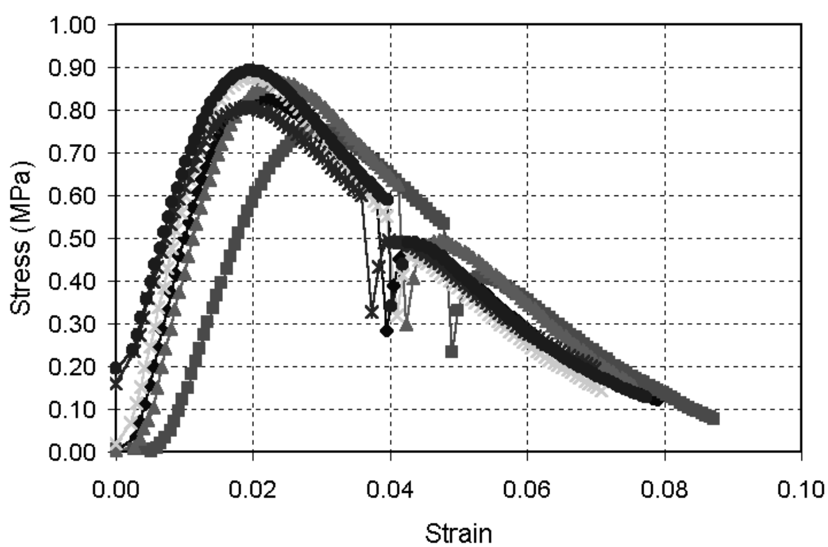
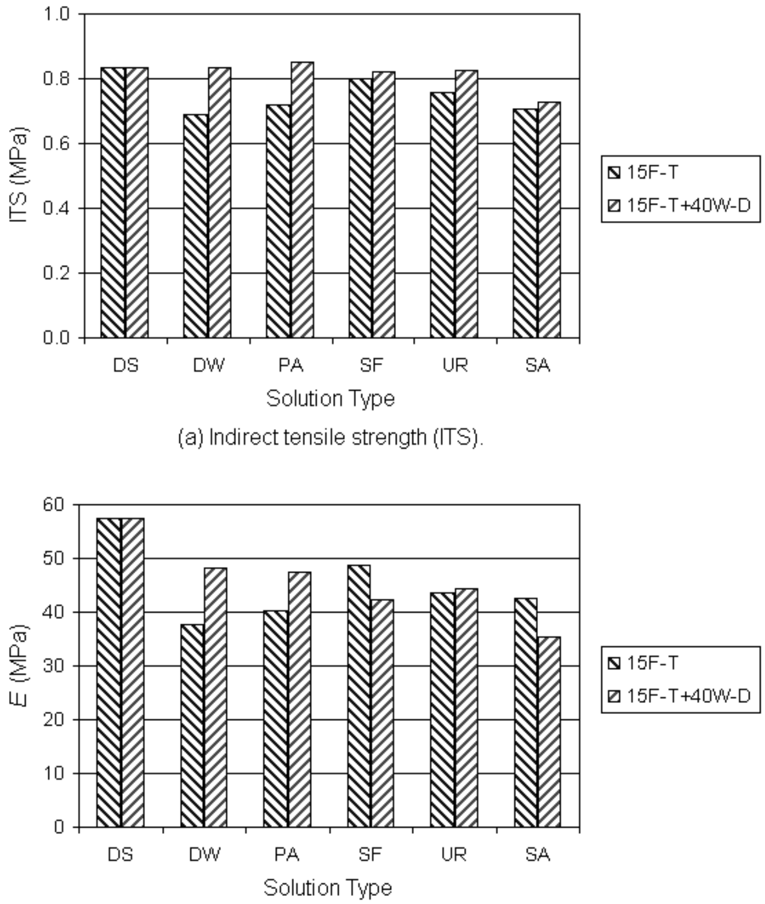


Figure V.
Example of stress-strain curves for dry samples.



(a) Indirect tensile strength (ITS).

(b) Elastic modulus (*E*).

Figure VI.
Summary of average indirect tensile strength test results.

Using the stress-strain curve of each sample, its indirect tensile strength (ITS), defined as the maximum stress according to Equation (1), or the peak stress in the stress-strain diagram, and the initial modulus of elasticity (*E*) were calculated. Figure VI shows a summary of the average ITS and *E* for each set of samples, respectively. It should be noted that the dry samples shown in both figures were not subjected to any freeze-thaw or wet-dry cycles.

As shown in the figure, the average ITS of samples subjected to 15 freeze-thaw cycles was lower than that of dry samples. However, samples immersed in all deicer solutions had a greater ITS than those immersed in distilled water, which showed the largest difference in the ITS compared to the dry samples. On the other hand, samples subjected to forty dry-wet cycles (in addition to the first 15 freeze-thaw cycles) had average ITS values that were very close to that of the dry samples. The notable exception was the samples immerse in sodium acetate where the average ITS was about 13% lower than the dry value. As for the elastic modulus, Figure VI shows that the change of *E* because of the freeze-thaw and dry-wet cycles was more significant than the change of ITS. Similar to the ITS, the lowest value of *E* after 15 freeze-thaw cycles was recorded for the samples immersed in distilled water. However, the change in *E*, relative to the dry samples, was still significant after the wet-dry cycles. Again, the samples immersed in sodium acetate recorded the lowest value of *E* after exposure to 15 freeze-thaw cycles and forty wet-dry cycles.

Extraction Test Results

After testing the samples for indirect tensile strength, the samples were grouped into 11 sets where each set consisted of the samples immersed in the same solution and subjected to the same number of cycles in addition to the set of dry samples. Each set underwent a series of tests aimed at examining the effect of exposure to deicers, freeze-thaw and wet-dry cycles on the characteristics of the mix components. These tests were extraction of bitumen (MTO standard test LS-282), recovery of bitumen (LS-284), penetration test of recovered bitumen (LS-200), and aggregate gradation of recovered aggregates (LS-602). All these tests were sub-contracted to Golder Associates Ltd. The results of recovered penetration are shown in Figure VII and the results of recovered gradation are shown in Table I.

After 15 freeze-thaw cycles, the penetration values of recovered asphalt cement shows that the penetration of the conditioned asphalt cement is higher than that of the dry samples for all cases except for the sodium formate exposed samples. The penetration of recovered asphalt of these latter samples was slightly less than that of dry samples. In addition, the samples conditioned in potassium acetate and sodium acetate had the highest penetration value. These results indicate that a softening had taken place in the asphalt cement. This implies that the freeze-thaw cycling caused softening of the asphalt cement, which could explain the reason for the decrease in the modulus of elasticity in these samples as the number of freeze-thaw cycles increased. After the wet-dry cycles, the recovered asphalt cement of samples immersed in all solutions had almost the same penetration, which was equal to that of the dry samples. Therefore, the wet-dry cycles caused the asphalt cement to harden again after it had been softened during the freeze-thaw cycle. The exception to this trend is the samples immersed in sodium formate where the penetration values of recovered asphalt after freeze-thaw and wet dry were very close to each other and close to that of the dry samples.

In order to assess the effect of this variable, it is assumed that gradation of the dry control samples is the “Base” to which all other gradations are to be compared. Clearly, if significant damage takes place as a result of the deicer, one should expect change (*an increase*) in the passing percentage of the different sieves. As shown in Table I, the results of the gradation analysis suggest that none of the deicers induced significant damage.

CONCLUDING REMARKS

Based on the results of the experimental investigation presented in this paper as well as the results of the earlier study, the following conclusions can be stated:

1. Asphalt concrete pavements exposed to freeze-thaw while saturated may suffer loss of tensile strength and elasticity, with or without a deicer in the liquid. However, after a large number of freeze-thaw cycles, the presence of urea in the liquid would cause disintegration of the pavement and a considerable loss of strength and elasticity.

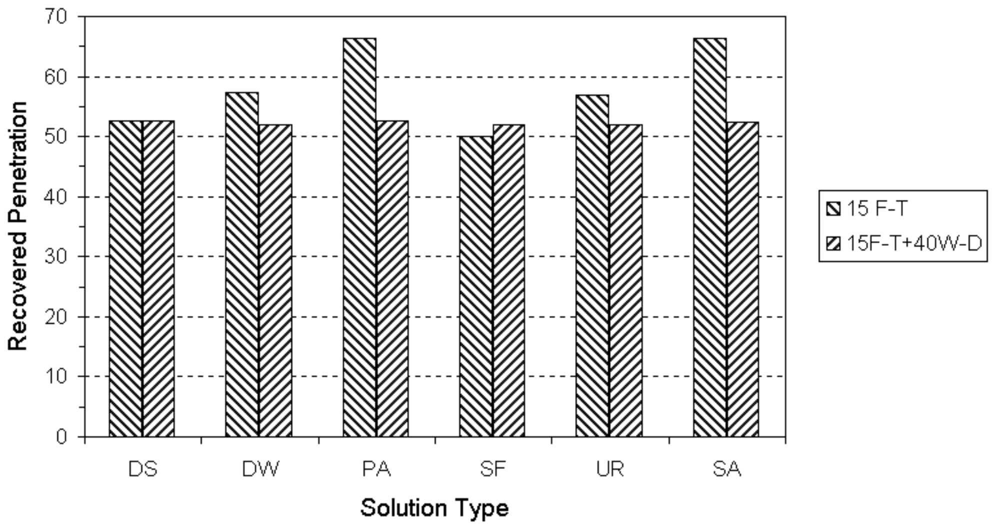


Figure VII.
Penetration test results of recovered bitumen.

Table I.
Gradation test results of recovered aggregates.

Sieve (mm)	Percent Passing										
	DS	After 15 F-T cycles					After 15 F-T + 40 W-D cycles				
		DW	PA	SF	UR	SA	DW	PA	SF	UR	SA
16.0							100				
13.2	100	100	100	100	100	100	97.6	100	100	100	100
9.50	97.2	97.0	96.6	96.4	96.6	98.1	92.4	95.0	97.1	95.8	94.9
4.75	69.0	71.3	69.1	66.9	70.1	71.6	67.8	69.6	70.1	67.6	67.7
2.36	49.2	50.7	49.3	48.3	50.4	51.4	48.8	50.3	50.3	48.5	49.1
1.18	33.3	34.2	32.9	33.5	34.6	34.9	33.2	34.0	34.7	33.5	33.4
No 600	21.9	13.8	20.9	22.1	22.6	22.8	21.6	22.2	22.9	21.7	22.2
No 300	14.0	8.3	12.4	14.2	14.2	14.4	13.6	13.8	14.7	13.4	14.2
No 150	8.7	5.5	6.9	8.7	8.5	8.8	8.3	8.4	9.2	8.0	8.9
No 75	6.1	3.7	4.1	6.1	5.8	6.1	5.7	5.6	6.4	5.3	6.3

2. A pavement exposed to freeze-thaw while immersed in a deicing solution will not suffer additional loss of strength or elasticity due to the succeeding wet-dry cycles during the warm seasons. With the exception of pavements exposed to sodium acetate, the strength and elasticity after warm wet-dry cycles were slightly higher than that before exposure to the wet-dry cycles.

3. In this study, sodium acetate is the only deicer that caused further loss of strength and elasticity as result of exposure to warm wet-dry cycles. Exposure to sodium acetate, combined with freeze-thaw and wet-dry cycles, caused about 13% loss of strength and 40% loss of elasticity. It should be noted that comparable exposure to distilled water caused no

strength loss and about 16% loss of elasticity. Loss of strength due to exposure to all other deicers was very close to that due to distilled water while loss of elasticity was slightly higher.

4. The results of penetration were in agreement with those of a previous study where it was shown that exposure to freeze-thaw causes a softening of the asphalt cement while exposure to deicers causes hardening. This was evident in the hardening experienced during the warm wet-dry cycles. It should be noted, however, that the magnitude of change in penetration of recovered asphalt was relatively small. That may be explained by the effect of aging on the asphalt cores recovered from the pavement in the previous study.

5. No significant difference was noticed between the gradations of recovered aggregates of exposed and dry samples. Therefore, the relative damage reported in the earlier study could be explained by the exposure to fifty freeze-thaw cycles.

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